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THE DAILY RAINFALL STATISTICAL SHIFT DURING THE HALF CENTURY OVER THE BRANTAS CATCHMENT, EAST JAVA

(Statistik Perubahan Curah Hujan Harian Selama Setengah Abad di Daerah Tangkapan Brantas, Jawa Timur)

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ABSTRAK

Penelitian bertujuan menganalisis perubahan curah hujan harian jangka panjang di wilayah tangkapan Sungai Brantas Jawa Timur. Penelitian ini relatif baru di negara ini karena kurangnya kualitas data yang baik dan menyebar merata di seluruh wilayah. Dengan data periode panjang yang berkualitas baik di wilayah tangkapan Brantas, kita dapat mendeteksi perubahan secara statistik curah hujan harian, perubahan antar periode dan frekuensi tren perubahan curah hujan mingguan, bulanan, tiga bulanan dan tahunan. Penelitian ini menggunakan beberapa metode termasuk perubahan distribusi pdf, uji trend menggunakan metode non parametrik Mann Kendall dan analisis wavelet. Perubahan jumlah curah hujan yang rendah terjadi dari musim kemarau ke musim hujan. Dari hasil penelitian ini ditemukan pengaruh yang signifikan dari orografi dan tahun ENSO dalam uji tren. Selanjutnya, hasil dari uji Mann Kendall menunjukkan bahwa tren hari hujan meningkat selama musim hujan dan periode transisi pertama, sebaliknya menurun pada musim kemarau dan periode transisi kedua.

Kata Kunci : Daerah tangkapan Brantas, curah hujan harian, Mann Kendall, Tahun ENSO

ABSTRACT

A study of long term shift of the daily rainfall over the Brantas catchment East Java was done. Such a study is relatively new for the country due to lack of good quality data and sparsely distributed data all over the region. With a good quality long-term daily rainfall data over the Brantas catchment, we could detect a statistical shift of amount of rainy days, shift between periods and frequency trend changes from weekly, monthly, three-monthly and annually. The study utilized several methods including the probability density function distribution shift, Mann Kendall non parametric trend test and the wavelet analyses. The shift of low amount rainfall occurs from the dry to the wet season. We found distinct influences of orography and ENSO years in our trend tests. Additionally, the result of the Mann Kendall test show that the trend of rainy days increase during the wet season and the second transition period, while decrease during the dry season and first transitional period. Meanwhile the El Nino and La Nina have significant influence toward the dry season and the second transitional period.

Keyword: Brantas catchment, daily rainfall, Mann Kendall, ENSO years

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INTRODUCTION

In the late 18th century, Arrhenius (1896) was the first to quantify the contribution of carbon dioxide to the greenhouse effect and to speculate about whether variations in the atmospheric concentration of carbon dioxide have contributed to long-term variations in climate. According to the IPCC report (IPCC, 2001, 2007), the surface temperature of the earth will rise steadily during the post industry era of the 19th century due to the trapped radiative energy in earth atmosphere. Long term study of rainfall variability and its change due to global climate change for local climate over the maritime continent has been quite rare. In their report, IPCC (2001) predicted a small change (below 5%) of rainfall over the Southeast region as resulted from inter-model consistency. Some of the impact of the global climate change is a change of rainfall pattern on a local or a regional scale such as the regime shift of the daily rainfall pattern. Has the daily rainfall pattern been changed as predicted over this region or has the rainfall regime shift has not been noticead? Such a question is very important nowadays, since during past decades, climate and weather is highly unpredictable and extremes such as drought and flood occur quite often.

On the regional scale, the study of local and regional impact of rainfall pattern change is quite rare, especially for Indonesian rainfall. Study of the character of Indonesian rainfall characteristics has been performed by Aldrian and Susanto (2003) and the regional rainfall climate modeling study has also been performed by Aldrian et al (2004). Meanwhile study on the characteristics of Java rainfall has also been discussed (Anzhar 1996). One of the interesting areas for such a study is the Brantas catchment area in east Java province. The climate over the Brantas catchment is dominated by a strong monsoonal system with a large contrast between the dry and rainy seasons and is strongly modulated by El Niño southern Oscillation (Aldrian and Susanto, 2003). The data from this area has been collected daily for quite a long time (more than five decades). With a good spatial and temporal coverage, those data is a valuable source of information of the local climatic changes could be assessed. Aldrian and Djamil (2007) discussed the long term climate trend of the rainfall over this catchment and found the decreasing trend of annual rainfall trend and annual pattern changes. Their work focuses on the monthly rainfall data from the catchment, while this study uses the daily rainfall data.

The Brantas catchment covers about 11050 km^2 or about 35% of the area of East Java Province. The total length of the river is 320 km, which goes around an active volcano the Mount Kelud, while the Brantas River itself is the second largest river in Java. The annual average of rainfall amount reaches 2000 mm and about 95% of those fells during the rainy season. Total potency of surface water reaches 12 billion m^3, while total dam capacity in the area reaches only 2.6 – 3 billion m^3 yearly. People live in the Brantas basin was about 13.7 million in 1994 (about 16 million nowadays) or about 43.2% of total East Java population. The population density over the basin area is about 1.5 times of the provincial average.

Considering the importance of the Brantas catchment area to the local and regional economy, a study of long-term rainfall pattern change is essential. The aim of this paper is to investigate the temporal statistical regime shift of daily precipitation in the Brantas catchment area, east Java, during the last five decades. The investigation focuses on extreme rainfall distribution and changes, trend of total rainy days and linear trends of weekly, three monthly, six monthly and annual frequencies based on daily data. Such a study is important for the regional change consequence of the global climate change and as a complement of previous two studies on the climate trend over the catchment (Aldrian and Djamil, 2007). In this study time series of monthly precipitation amounts of 40 rain gauge stations during 1955–2005 were analyzed. The methods used in order to achieve the objectives of the study are the probability density function analysis, nonparametric tests and wavelet method. The study is limited to temporal analyses from daily to decadal. In doing so, the outline of the study is divided into the following; the next section will discuss the data and method of analyses follows by some results. Then, we will discuss some topics related to various result and the final section will be concluded by some highlights found in this study.

Study Area

The Brantas River originates near the volcano Arjuno, streams southward, westward, northward and diverts into three branches in the coastal lowlands (Fig. 1) near the provincial capital Surabaya. The source of Brantas is surrounded by high mountains. According to Nieuwolt (1975) mountainous region shall receive more rainfall in comparison to the lowland area due to orographic effect. The climate is dominated by the monsoons, but in contrast to the western part of the island eastern Java experiences only one wet season during the months November-April with an average annual rainfall of 2330 mm (average of 1991 to 2005). Nowadays, approximately 16 million people live in and on the resources of the Brantas area. Rapid demographic changes and pressure from population in the 20th century have altered Java's landscape and ecology.

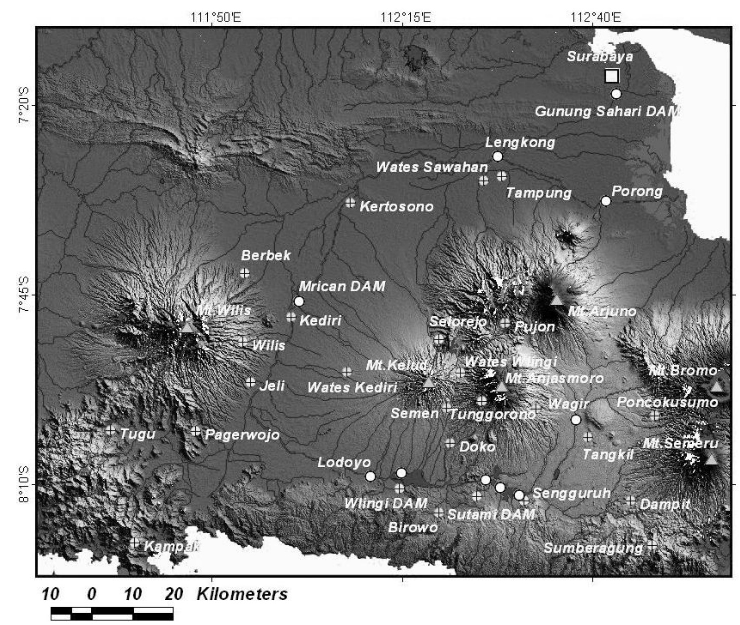

Figure 1. Rain gauge stations ⊕ and discharge stations ○f Brantas catchment.

Rainfall Data

Rainfall, hydrology and water quality data of the Brantas River has been collected and managed by the Perum Jasa Tirta I (PJT I) as the catchment regional authority. The Brantas River hydrometeorology data has been the best data collection for a catchment in Indonesia so far. The daily rainfall data is available since 1955 from 26 rain gauge stations (see Fig. 1), while the hydrology and water quality since 1991. Moreover, since 1991, the local authority has modernized the data collection using an integrated automatic telemetry system for rainfall and hydrology data. Some station locations were changed since 1991 while about 13 stations remains in their places from 1955 onward. From the 13 stations that has not moved, 2 stations; Doko and Dampit have some missing data between 1955 and 2005. In Doko the rainfall between 1980 and 1990 is not available. Meanwhile the Dampit station has missing data from 1984 to 1989. Hence, in overall the data from both stations could not be used for the analyses and only the remaining 11 station are used in this study. Those stations are well distributed from the upstream to downstream and from high to lowland altitude locations.

Table 1. Station names and locations, source : Perum Jasa Tirta I.

No.	Station name	Longitude	Latitude	Station height (m)
1	Kertosono	E112.138	S7.549	47
2	Kediri	E112.007	S7.799	70
3	Tugu	E111.612	S8.048	118
4	Wates Kediri	E112.131	S7.799	175
5	Birowo	E112.331	S8.229	195
6	Tangkil	E112.657	S8.063	395
7	Wagir	E112.544	S8.001	480
8	Wates Sawahan	E111.815	S7.702	620
9	Semen	E112.348	S7.999	625
10	Poncokusumo	E112.805	S8.015	1120
11	Pujon	E112.477	S7.812	1258

Method

One of the methods for detecting rainfall regime change during the last half century is by grouping the daily rainfall intensity according to the season and half decade. In this approach we classify the season into rainy season from December to February, dry season from June to August and two transitional seasons. The first transitional season from March to May represents the period after the wet to the dry season and the second transitional season from September to November represents the period after the dry to the wet season. The grouping of the daily rainfall was done by grouping the rainfall intensity every 10 mm starting from a group below 10mm, between 10 to 20mm and so on until the group of rainfall intensity above 110 mm. In doing so we establish the change in the probability density function of each above groups during the last half century by grouping in each five year period. In addition extreme rainfall distribution along with its shift during that period will be also described.

The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \quad (1)$$

where $f(t_i)$ is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. We want to test the null hypothesis of no trend, H_o, i.e. the observations x_i are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. Our computation exploits the normal approximation (Zstatistics).

The Mann-Kendall test statistic S is calculated using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \quad (2)$$

where x_j and x_k are the annual values in years j and k, $j > k$, respectively, and

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 & if \ x_j - x_k > 0 \\ 0 & if \ x_j - x_k = 0 \\ -1 & if \ x_j - x_k < 0 \end{cases} \quad (3)$$

If n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1987). The two-tailed test is used for four different significance levels α: 0.1, 0.05, 0.01 and 0.001. At certain probability level H_o is rejected in favor of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend. In our case, again the seasonality divides one year into four periods that represent the wet and dry seasons and two transitional periods as mentioned before. The application of this method will focus on the trend of total rainy days during the latest half century.

The wavelet transform is an extension of the Fourier Transform method or a running (windowed) FFT method, using a certain window size and sliding it along in time, computing the FFT at each time using only the data within the window. The wavelet analysis (Torrence and Compo, 1998) works furthermore by attempting to decompose a time series into time/frequency space simultaneously. One gets information on both the amplitude of any "periodic" signals within the series, and how this amplitude varies with time. The method will calculate the power spectrum of data series. The wavelet analysis in this study is calculated using the Morlet mother wavelet for the power and global spectra. In this study, we are interested in the annual trend of rainfall. The method is applied on all continuous station data and then we calculate the linear trend as well as the corresponding statistical significance using the Mann Kendall trend test. In this study, the weekly, three monthly, six monthly and annual trend analyses of daily rainfall during the latest half of the century was performed. They are associated with the high frequency, intra seasonal, monsoonal and annual trends, respectively.

RESULTS AND DISCUSSION

Probability density function analyses

From all station of the catchment, the distribution of the rainy days skews to the right or the positive skewness (Nasution and Barizi, 1976). High rainfall amount is located in the right and low amount in the left. The left and right end of the curve indicate both low and high extreme. Generally, changes of the low amount rainfall are more obvious than in the high rainfall amount since 1955. This method could not show changes of high rainfall amount during the same period especially when originally we divided the monthly data in decadal period. Later on, data are grouped into three monthly rainy days according to season on annual basis, instead of decadal basis as before. Changes are presented in five yearly basis from 1955. Again, the result shows that low amount rainfall regime has change significantly. During the rainy days, station such as Pujon, Poncokusumo, Semen and Wagir experience increase of rainy days in comparison to other stations the increase of extreme rainfall occur in rainfall amount more than 110mm. Meanwhile during the dry period and the second transitional period, there is no noticeable change except in Wagir and Semen. In Wagir there is a slight increase of rainy days in high and low amount of rainfall, while in Semen the decrease of rainy days for high rainfall amount and increase of rainy day for the low rainfall amount, although the latter changes is unnoticeable.

Table 2. Number of rainy days (x) of Semen during rainy season (December-February).

Year	Rainy days (x) for respective scale (mm)											
	0<x≤10	10<x≤20	20<x≤30	30<x≤40	40<x≤50	50<x≤60	60<x≤70	70<x≤80	80<x≤90	90<x≤100	100<x≤110	x>110
1955-1959	60	54	32	23	18	8	2	5	2	8	2	2
1960-1964	54	65	24	16	13	6	4	3	2	0	1	6
1965-1969	42	36	23	35	12	4	6	4	2	1	1	0
1970-1974	42	36	34	23	6	6	2	4	3	2	1	2
1975-1979	52	40	24	20	14	8	7	7	3	4	1	1
1980-1984	57	43	38	21	17	13	4	6	2	3	0	0
1985-1989	171	65	40	19	14	5	1	4	1	3	0	4
1990-1994	141	55	43	36	11	11	11	8	6	1	6	3
1995-1999	169	60	27	25	16	10	6	5	2	1	0	6
2000-2004	143	54	37	27	17	15	8	4	4	3	1	2

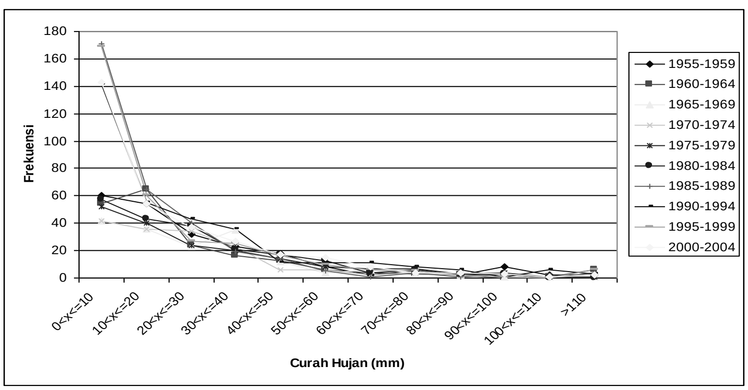

Figure 2. The *Probability density function* (PDF) for December to February data for Semen station.

Mann Kendal analyses

The Mann-Kendall trend test was used to test the independence, trend and determine the linear regression model. The trend of changes during the dry season is insignificant due to low number of rainy days in that season. Thus small changes of rainy days in that season will be unnoticeable. The trend during the wet season and the second transition period tend to increase while during the dry season and the first transition period tend to decrease. The latter fact indicates the move of rainy days from the dry period into the wet period. Such phenomenon occurs in all stations except in Kediri and Wates Sawahan. This finding is in accordance to those in Aldrian and Djamil (2007), in which most stations indicate rainfall reductions over the dry period and increasing ratio of wet period proportion to the annual rainfall. In comparison to previous analyses on probability density function there is an increase in low amount rainfall during the wet season. Therefore the result indicates a shift of rainy days with low amount rainfall from the dry to the wet season.

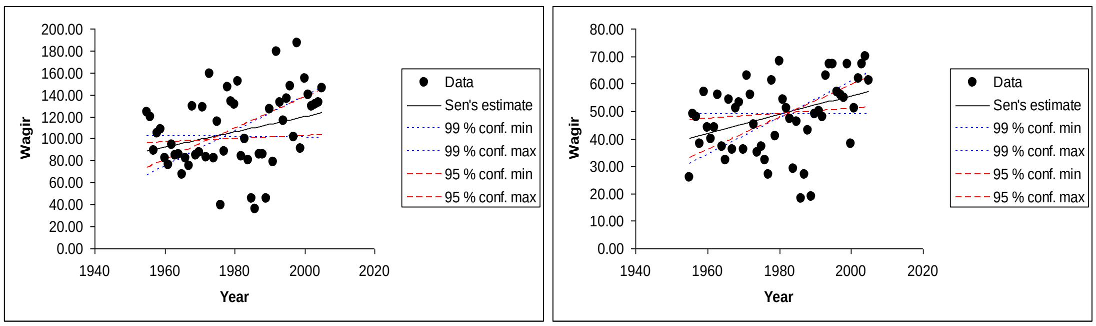

Figure 3. An Example of Mann Kendall trend test from annual rainfall (left) and December to February or wet season rainfall (right) for Wagir station.

Table 3. The Mann Kendall trend test indicator (Z) among different stations and in several seasons with and without ENSO years

Stations	height (m)	including El Nino La Nina years				without El Nino La Nina years			
		wet season	first transition	dry season	second transition	wet season	first transition	dry season	second transition
Kertosono	47	1.33	0.48	-0.98	0.38	0.67	0.19	-0.93	1.02
Kediri	70	0.61	0.35	0.55	0.72	-0.16	-0.56	0.03	1.37
Tugu	118	1.55	-0.38	-0.04	1.13	0.65	-0.51	-0.37	*2.22
Wates Kediri	175	0.92	0.07	-0.68	0.63	-1.11	-0.45	-0.78	1.34
Birowo	195	*2.52	-0.23	-0.24	1.02	1.35	-0.07	-0.87	+1.81
Tangkil	395	1.48	-0.51	-0.62	1.04	0.75	-0.81	-0.93	+1.73
Wagir	480	**2.6	**2.92	0.93	1.54	1.59	*2.1	0.45	*2.14
Wates Sawahan	620	-0.69	-1.95	-1.53	0.4	-1.51	*-2.36	-1.7	0.72
Semen	625	***4.36	***3.54	1.54	**3.12	***3.37	*2.36	+0.92	**2.84
Poncokusumo	1120	**2.72	1.29	0.07	1.52	1.52	0.81	-0.26	+1.85
Pujon	1258	-1.27	-1.28	-0.56	-0.07	*-2.01	-1.34	-0.67	1.09

Note : (+,*,**,*** indicate statistical significance 90%, 95%, 99% and 99.99%).

The implication of the station height to the trend changes is obvious where stations of high altitude have more significant changes than the lowland stations. The reason for this phenomenon is the orographic effect that produces high intensity rainfall more than the lowland stations. Another importance implication to the variability of trend is the impact of ENSO (El Nino and La Nina) episode. In this study we performed calculations by including and disregard the ENSO years. From 1955 to 200, the El Nino years are 1965, 1969, 1972, 1982, 1987, 1991, 1997 and 2002. While the La Nina years are 1955, 1964, 1970, 1973, 1975, 1988, 1998, 1999. Most of cases, the trend with ENSO years will have larger gradient of trends than the non ENSO trends. The trend during the dry season and the second transition periods with and without El Nino and La Nina episode is significantly different. Thus the impact of El Nino and La Nina are more obvious during the dry and the second transition periods than during the other two periods.

Wavelet analysis

The analysis of rainfall amount changes of the Brantas catchment using the wavelet method was divided into different frequencies; the weekly, three monthly, six monthly and annually. For the weekly frequency there is a decreasing tendency of extreme rainfall in all stations except in Kediri, Wagir and Semen. Since the data are taken from the whole year period, the result is slightly different from the result of the Mann-Kendall statistic test. If the data are grouped into three-monthly basis, the result would be the same.

Table 4. The regression line gradients from wavelet time series.

No	Station	height (m)	Periods				
			weekly	Intra Seasonal/ MJO (3 months)	Semi Annual (6 months)	Annual (yearly)	Annual (Aldrian and Djamil, 2007)
1	Kertosono	47	-0.056	0.003	0.031	-0.001	-0.0187
2	Kediri	70	0.054	0.025	0.025	0.012	-0.0061
3	Tugu	118	-0.020	0.014	0.005	-0.008	-0.0254
4	Wates Kediri	175	-0.067	0.842	0.029	0.010	-0.0092
5	Birowo	195	-0.036	-0.019	0.003	0.002	-0.0137
6	Tangkil	395	-0.070	-0.007	0.005	-0.009	-0.0260
7	Wagir	480	0.031	0.016	0.020	0.006	-0.0085
8	Wates Sawahan	620	-0.083	0.042	0.006	0.001	-0.0147
9	Semen	625	0.029	0.029	0.025	0.026	0.0107
10	Poncokusumo	1120	-0.051	-0.001	-0.013	0.002	-0.0125
11	Pujon	1258	-0.067	0.027	0.024	0.010	-0.0146

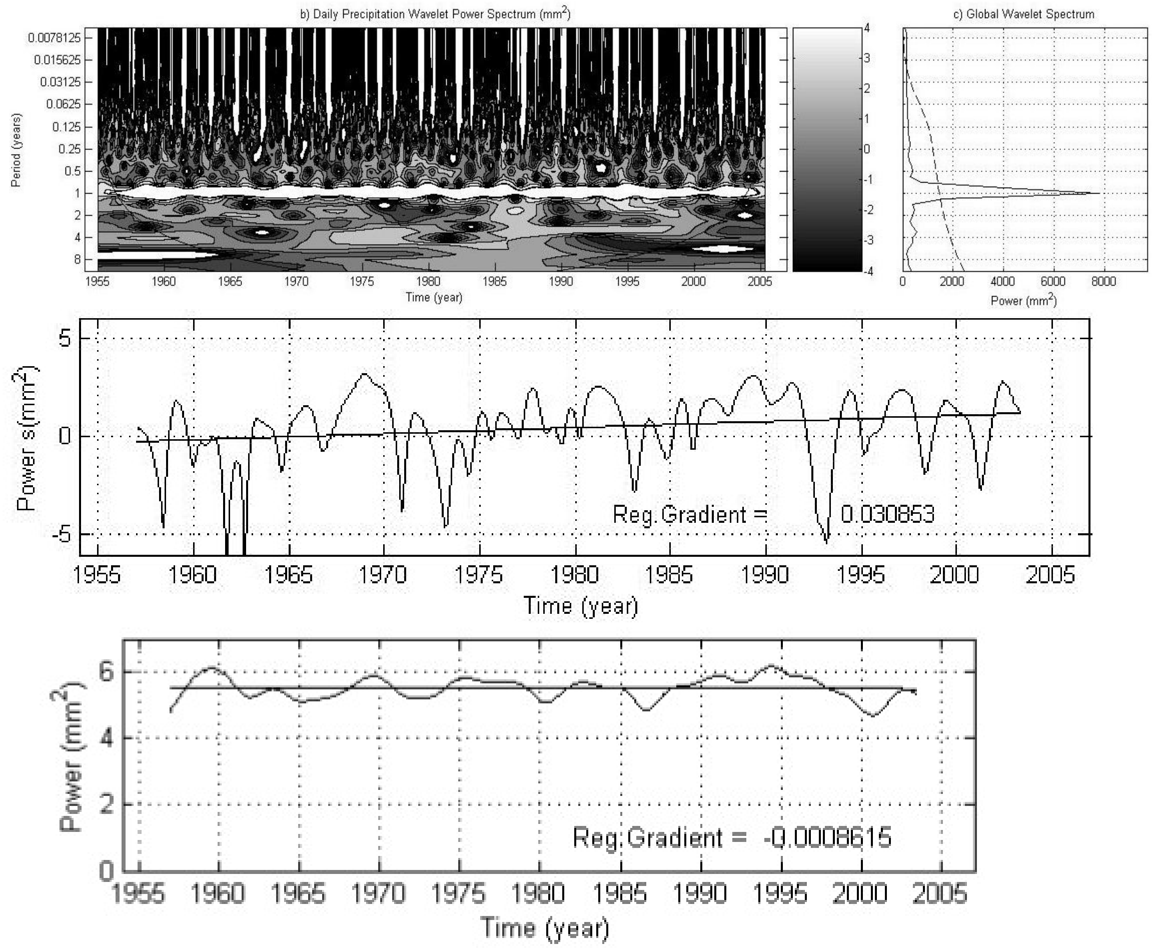

Figure 4 . Wavelet analyses (top) of monthly (middle) and annual (below) signals from Kertosono station.

The high frequency signal (weekly) indicates a weakening trend. The trend for the three-monthly period shows the trend of the intra seasonal activity during the past half century over this region. These intra seasonal signals are affected by the Madden Julian Oscillation (MJO). From all stations, the influence of MJO tend to increase except for the Birowo, Tangkil and Poncokusumo. The trend for the semi-annual period (six-monthly) as the implication of the monsoonal activity show increase in all stations except for the Poncokusumo. Meanwhile, for the annual activity, the wavelet signal shows increasing trend for all stations except Kertosono, Tugu and Tangkil. The semi-annual and annual signals indicate the strengthening activity of the monsoonal activity over the Brantas catchment. This result is opposite to that of the Aldrian and Djamil (2007) who found the weakening monsoonal signal. In their study data are monthly and in this study is daily. Beside, the weakening signal by that study is much more prominent than the result of this study. Hence, by comparing the result of this study and that by Aldrian and Djamil (2007) the result of detecting annual trend is better when using monthly data rather than daily data. The daily data is better to detect high frequency signals. The latter fact is supported by the comparing the result of weekly trend (this study) and annual trend (Aldrian and Djamil, 2007). Therefore, the method in this study is more suitable for higher frequency analysis less than one month period. While for the annual trend, the monthly data is more suitable.

CONCLUSIONS

Analyses of rainfall regime shift over the Brantas catchment area during the last half century has been performed with three different analyses methods. With the probability density function analyses, the distribution pattern of rainy days and the number of extreme rainfall days are clearly seen. The results show that the shift of extreme rainfall above 110mm is obvious in high altitude region in comparison to the lowland area. The low rainfall amount (below 10mm) days do not change significantly while there are increase and decrease at certain period and no obvious trend in general.

The result of the Mann Kendall test show that the trend of rainy days increase during the wet season and the second transition period, while decrease during the dry season and first transitional period. Meanwhile the El Nino and La Nina have significant influence toward the dry season and the second transitional period.

The result of the wavelet method shows weakening weekly spectra in almost all stations. Meanwhile for the three monthly, there is an increase trend in nine stations and almost station have increase trend for the semi-annual and annual signals. In general, from the PDF and Mann Kendall analyses, the shifts of extreme rainfall are noticeable in the wet season and in high altitude regions. Thus, there is shift of rainy days from the dry period to the wet period especially in rainfall intensity below 10mm for the Brantas catchment area.

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